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Imaging floating metals and dielectric objects using electrical capacitance tomography

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ABSTRACT

Electrical capacitance tomography (ECT) is a well-established industrial process tomography technique. The application of ECT is generally limited to imaging insulating objects with permittivity contrast. Although ECT imaging for grounded conductors are studied earlier, there is not a systematic study of imaging floating metals using ECT. To broaden the application of the ECT, imaging of suspended metallic samples is studied in this paper. Placing a metallic conductor between electrodes has an effect of shortening the spacing between the electrodes, thus the capacitances are increased. This increment in capacitances can be regarded as placing a dielectric sample with higher permittivity than the reference data. An ECT image of the floating metallic samples can be reconstructed using traditional sensitivity based image reconstruction, which is in the same way as imaging dielectric permittivity. In this paper, both metallic and dielectric samples are tested, and the results show the feasibility of ECT imaging for floating metals.

1. Introduction

Electrical capacitance tomography (ECT) is a non-invasive method which produces tomograms of permittivity distributions by using capacitance measurements of material under test [1,2]. Generally, ECT is considered as a suitable imaging tool for dielectric materials. In many application areas the material under test may not be a purely dielectric, but a mixture of dielectric and conductive. For low conductivity samples, such as saline water, the conductivity could decrease the ability of ECT to image the dielectric sample within the conductive background [3,4], study of low conductivity materials in ECT is beyond scope of this paper and are presented elsewhere [5]. ECT with grounded conductors are studied earlier [6,7].

For grounded metal in known location, Ville Rimpiläinen et al. set the boundary condition of metal to zero voltage to solve the problem of grounded conductor shaft in a mixer [7]. For the grounded metal of unknown location, Maomao Zhang et al. introduce MIT to find the location of metal and image the dielectric contrast in the remaining area in the sensor [6]. On the other hand, for the floating metal, the conducting surface is equipotential but not in the voltage of zero. The floating metal between electrodes will increase the measured capacitance due to the reduction in spacing between the electrodes. Dixiang Chen et al. designed a security screening system using a planar capacitance sensor matrix to generate an image of an floating steel sample [8]. However the tomographic method has not been used in their screening system, the steel sample is directly imaged by the capacitance measurement of the planar sensor. In our ECT experiments, by calculating this capacitance change caused by the metallic sample in ECT, an illusion of the permittivity change is reconstructed at the location of the metallic

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sample. A combination of permittivity change and presence of metal sample can also be imaged using ECT. Imaging metallic samples using ECT can be potentially very useful in various areas. Possibility of metal flow imaging using ECT can be very interesting. Simultaneous reconstruction of metallic samples and dielectric samples using ECT can provide a novel solution in many non-destructive evaluation applications where there is a mixture of conductive and dielectric medium.

This paper presents imaging metallic samples and simultaneous imaging of metallic samples and dielectric samples for the first time. Analysis of metallic sample as floating and grounded conductors is shown in simple capacitance measurement enabling a better understanding of metallic imaging using ECT.

2. Methodology

2.1. Forward model

To solve the image reconstruction problem a forward problem needs to be solved. A complex value ECT forward model is needed to analyse the ECT forward problem including both conductive and dielectric materials. From Maxwell's equations, the relationship between permittivity and conductivity distribution $\varepsilon(x)$, $\sigma(x)$ and electrical potential $u(x)$ are in the following way within the region, where

$$\nabla \cdot \left(\varepsilon(x) + \frac{\sigma(x)}{j\omega}\right)\nabla u(x) = 0 \quad (1)$$

And the boundary conditions of this problem are the electric potential $u(x)$ on different surfaces of the sensors.

$$u(x) = V \quad \text{on} \quad \Gamma_{\text{excited}} \quad (2)$$

$$u(x) = 0 \quad \text{on} \quad \Gamma_{\text{Screening}} \quad \text{and} \quad \Gamma_{\text{unexcited}} \quad (3)$$

where the V is the excitation voltage, Γ_{excited} is the surface of the excited electrode, $\Gamma_{\text{Screening}}$ is the surface of the screening and $\Gamma_{\text{unexcited}}$ is the surface of the unexcited electrodes. Fig. 1 shows the ECT sensor array with grounded and floating metallic inclusions.

In electrical quasi-static mode, a metal sample of high conductivity performs as an equipotential body, i.e. the electrical voltage drops on the metal is negligible. When the conductor is grounded, except for that the voltage potential remains the same within the region of conductor, the value of the voltage on the conductor is zero. The boundary conditions are changed as well. For ECT forward model including dielectric and conductor, to image the dielectric components is also in need in ECT. In forward models of ECT, different settings are applied to grounded and floating conductor.

1. In the case of grounded conductor, to image the rest region excluding the conductors, the forward model of ECT can be modified since the boundary condition of the sensing domain is changed. The grounded metal is set as an extra grounded "electrode", the voltage potential remains at zero [6]. The reference measurement is also updated: a measurement of the grounded metal standing in the sensor is used.
2. In the case of a floating conductor in ECT, the settings are different in electrostatic model or electro-quasi-static one. If the static model is used in forward problem, the region of metal is set as the same voltage but still unknown. Then the voltage will be calculated in forward model. If it is electro-quasi-static mode, every element in the mesh has a complex permittivity, which consists of both permittivity (ε) and conductivity (σ) with signal frequency (ω), i.e.

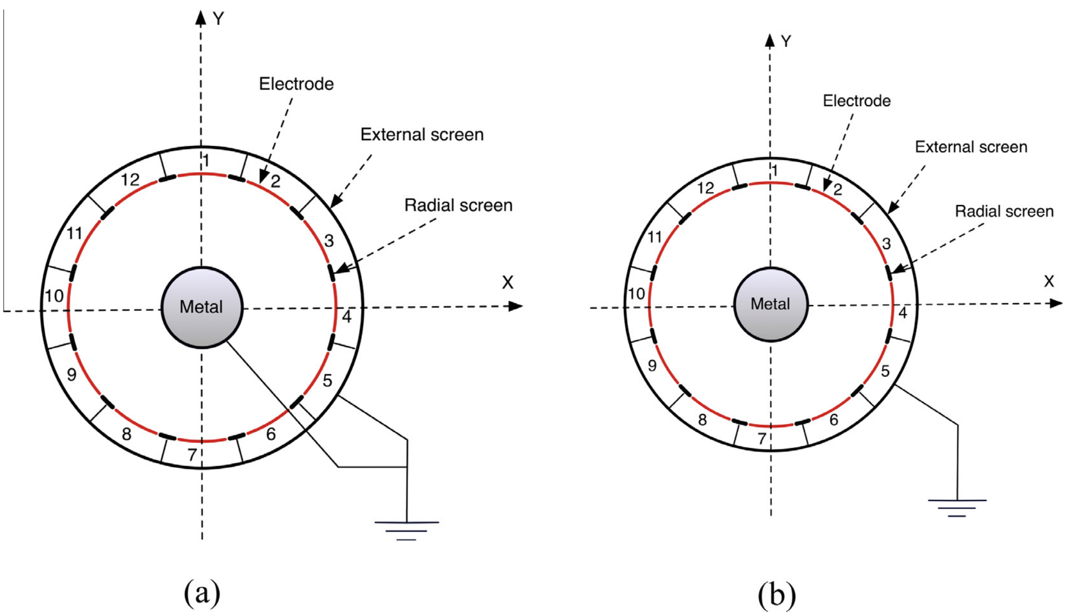

Fig. 1. Schematic drawings about cross section of a 12-electrode ECT sensor with (a) grounded metal or (b) floating metal.